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Stimulating *in situ* denitrification in an aerobic, highly permeable municipal drinking water aquifer

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ABSTRACT

A preliminary trial of a cross-injection system (CIS) was designed to stimulate *in situ* denitrification in an aquifer servicing an urban community in southern Ontario. It was hypothesized that this remedial strategy could be used to reduce groundwater nitrate in the aquifer such that it could remain in use as a municipal supply until the beneficial effects of local reduced nutrient loadings lead to long-term water quality improvement at the wellfield. The CIS application involved injecting a carbon source (acetate) into the subsurface using an injection-extraction well pair positioned perpendicular to the regional flow direction, up-gradient of the water supply wells, with the objective of stimulating native denitrifying bacteria. The pilot remedial strategy was targeted in a high nitrate flux zone within an aerobic and heterogeneous section of the glacial sand and gravel aquifer. Acetate injections were performed at intervals ranging from daily to bi-daily. The carbon additions led to general declines in dissolved oxygen concentrations; decreases in nitrate concentration were localized in aquifer layers where velocities were estimated to be less than 0.5 m/day. NO_3-^{15}N and NO_3-^{18}O isotope data indicated the nitrate losses were due to denitrification. Relatively little nitrate was removed from groundwater in the more permeable strata, where velocities were estimated to be on the order of 18 m/day or greater. Overall, about 11 percent of the nitrate mass passing through the treatment zone was removed. This work demonstrates that stimulating *in situ* denitrification in an aerobic, highly conductive aquifer is challenging but achievable. Further work is needed to increase rates of denitrification in the most permeable units of the aquifer.

1. Introduction

The accumulation of nitrate in the subsurface from agricultural operations has drawn international attention. Concern regarding this contaminant is driven by its high mobility in groundwater, and widely accepted links to various health conditions, such as methemoglobinemia (Gelberg et al., 1999; Johnson et al., 1987; Knobeloch et al., 2000) and an assortment of gastrointestinal cancers (Ward et al., 1996; Yang et al., 1998). As a result, various mandatory and voluntary standards for agricultural practice have been established in some jurisdictions to limit loadings to the subsurface. These beneficial management practices (BMPs) include any action that considers the balance of nutrients in agriculture – with an overall goal of protecting environmental resources – without sacrificing crop production (Crop Nutrients Council, 2009). Examples of such efforts include crop rotation, reduction of nutrient application rates, synchronisation of nitrogen supply and plant demand, the use of buffer strips and riparian zones, and the use of cover

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crops (Di and Cameron, 2002; Dinnes et al., 2002; Mckague et al., 2005). These strategies have been demonstrated to reduce the environmental impact of agriculture on groundwater systems. However, the time interval, or lag, between BMP implementation and a noticeable improvement in groundwater quality can range from years to decades (Cole, 2008; Honisch et al., 2002; Meissner et al., 2002; Tomer and Burkart, 2003; Wassenaar et al., 2006). A possible approach for mitigating the risk during the lag period is to adopt groundwater remediation strategies based on biostimulation as part of an integrated water quality management plan. A key advantage to this approach over the construction of an above ground water treatment facility is that it capitalizes on the natural capability of the subsurface to reduce nitrate concentrations utilizing a relatively low cost and low maintenance approach, which can be established on a temporary basis as opposed to the requirement to implement expensive surface treatment infrastructure that may only be required for a short time period.

The objectives of this research focused on a field application of the integrated approach, with emphasis on evaluating the biostimulation phase. Previous experiments related to *in situ* denitrification have not focused on the issue of heterogeneity to the degree it was observed here. In this case, it was hypothesized that *in situ* denitrification could also be initiated in highly permeable, heterogeneous, and aerobic aquifers through the introduction of a carbon source (i.e., an electron donor) using an appropriate injection system. The reduction in groundwater nitrogen through this remedial approach may provide an interim improvement in groundwater quality while regional BMPs gradually become fully effective. The field experiments were located at a site where elevated nitrate concentrations had been documented in municipal water wells.

2. Background

2.1. Physical setting and site history

The City of Woodstock, Ontario, Canada relies on groundwater to meet all domestic and industrial water demands. The Thornton Well Field, located adjacent to the study site in a rural setting southwest of the city, provides the majority of the water supply augmented by the Tabor Well Field further to the southeast (Fig. 1). The wells are completed in stratigraphically complex glacial overburden sediments of Quaternary age consisting of outwash sands and gravels intermingled with spatially discontinuous silty till aquitard units (Haslauer, 2005). The public supply wells are completed to an average depth of approximately 30 m within the glacial drift sediments. The surface is characterized by gently rolling topography with drumlin features and swales with a total relief of approximately 40 m over the study area. The average annual precipitation is between 900 and 1000 mm (Haslauer, 2005). The agricultural practices in the area are dominated by corn-soy bean-wheat rotation with historical hog and beef cattle enterprises.

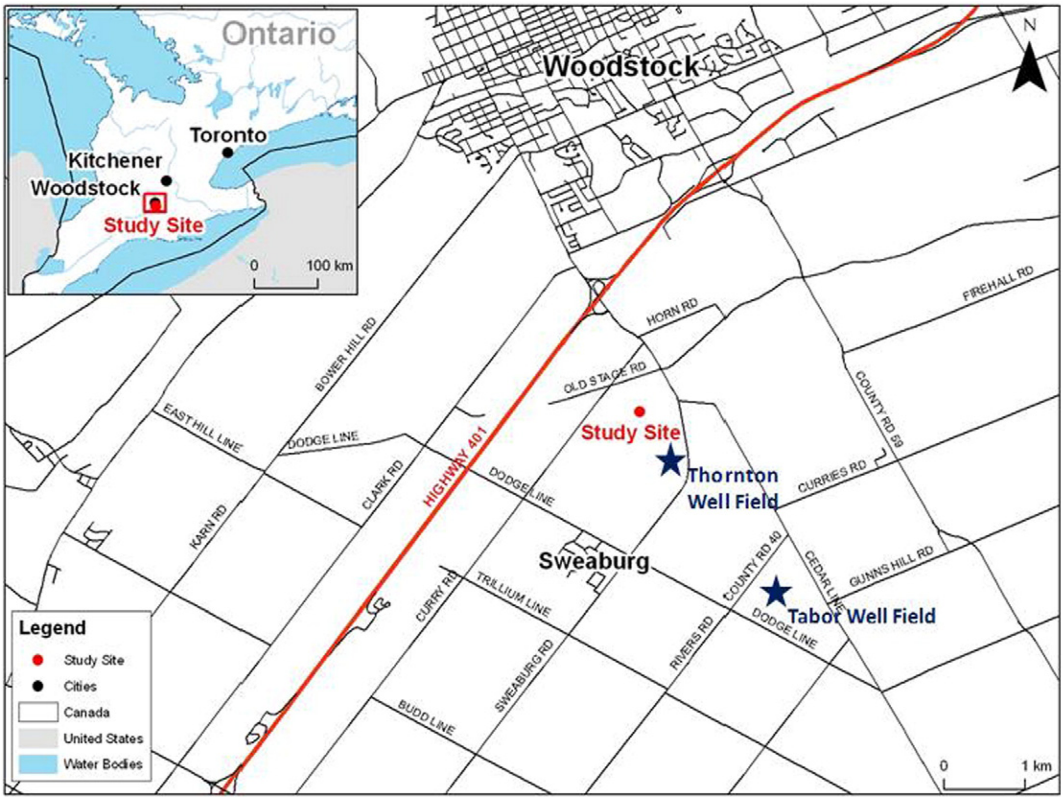

Fig. 1. Location of Study Site and major well fields providing municipal water to the City of Woodstock, Ontario.